Signs in the heavens: in recent years, fast radio bursts coming from the depths of space have been detected by telescopes like the one at the Arecibo Observatory.

IMAGE: JASON HESSELS-ASTRON / DANIELLE FUTSELAAR-ARTSOURCE.NL / B.P. IRWIN / D. VAN DE WATER / SHUTTERSTOCK

THE MYSTERY OF THE HEAVENLY BURSTS

TEXT: HELMUT HORNUNG

A cosmic lightning storm is playing out all around us. At any given moment, somewhere in the sky, a burst of radiation flashes and then fades away. Only observable with radio telescopes, these bursts last one-thousandth of a second and are one of astrophysics' greatest mysteries. Scientists rather doubt this is evidence of warlike aliens fighting "star wars" in the vastness of space. Experts have named them "fast radio bursts" – but where do they come from?

The Parkes Observatory in Australia is a gigantic dish of metal mesh gazing at the sky. With a diameter of 64 meters, this radio telescope was once the largest fully mobile radio telescope in the Southern Hemisphere. It registered a very mysterious radio burst in 2001, and nobody noticed it! It wasn't until five years later that astrophysicist Duncan Lorimer and his student David Narkevic stumbled upon the signature of the signal in the telescope data virtually by chance. Even then, the specialists couldn't make sense of the phenomenon. But this was not the only "Lorimer burst" to be discovered.

"We now know of more than a hundred," says Laura Spitler. Since March 2019, Spitler has headed a Lise Meitner Research Group on fast radio bursts (FRBs) at the Max Planck Institute for Radio Astronomy. Spitler has dedicated herself to these transient flickers in space for many years. In 2014, an international team under her leadership discovered the first FRB in the Northern Hemisphere in the constellation of Auriga. At the time, the astronomers were making observations in Puerto Rico using the dish of the Arecibo Observatory. This dish, with a diameter of 305 meters, is constructed and supported in a natural depression and can only focus on a relatively small section of the sky.

"Statistically, only seven eruptions should occur per minute, dispersed over the entire sky. So it takes a lot of luck to align your telescope to the right position at the right time," said Spitler after announcing her discovery. The properties of the observed radio flash and the derived frequency of such events closely matched the data obtained by astronomers for all previously recorded bursts.

The findings did indeed confirm statistical estimates that about 10,000 of these unusual cosmic phenomena flare up somewhere in the sky every single day. This astonishingly large figure was reached by calculating how much of the sky would have to be observed and for how long, in an attempt to explain the comparatively few observations made to date.

The Arecibo observation also removed the last doubts about whether the radio bursts really come from the depths of the universe. After the discovery of the first bursts, scientists had suggested that they were being generated way beyond the Milky Way. This was deduced utilizing an effect known as "plasma dispersion." Radio signals that travel a long distance through the universe collide

⟶

PHOTO: HENNING ROSS

Pursuing the mystery: Laura Spitler researches fast radio bursts (FRBs) at the Max Planck Institute for Radio Astronomy.

SUMMARY

Fast radio bursts last only a thousandth of a second and were discovered by chance almost 15 years ago.

They originate from galaxies at great distances and appear to be produced in different environments.

Astronomers now know that more or less regularly repeating radio bursts,known as "repeaters", also exist. The source of the radio bursts is still unknown.

with a large number of free electrons in interstellar space. Plasma dispersion decreases the velocity of lower-frequency radio waves producing a characteristic spread in the frequencies of the signal. The dispersion of the radiation burst discovered at the Arecibo Observatory was three times larger than would be expected from a source within the Milky Way.

But where do the radio bursts come from? Are they really from aliens using huge light sails to propel space probes? This idea was originally put forward by Abraham Loeb – a researcher at the renowned institution of Harvard University no less – and was recently seized on by the media. But most astrophysicists believe the bursts have a natural source and have come up with diverse explanations – all of them relatively bizarre. Many of these potential scenarios involve neutron stars. Neutron stars, only 20 kilometers in diameter, are the remnants of the massive explosions, known as supernovae, of high-mass stars.

Matter is so densely packed in a neutron star that on Earth's surface, one teaspoonful of it would weigh about as much as Germany's Zugspitze massif mountain. Neutron stars rotate rapidly around their axis, and some of them have exceptionally strong magnetic fields. Explanations for FRBs have varied. They may be generated during supernovae themselves, or perhaps during the fusion of two neutron stars in a compact double system as the magnetic fields of both stars collapse simultaneously. Or perhaps a neutron star collapses still further to create a black hole and this generates a burst.

Such scientific scenarios initially sound plausible. However, they have one flaw: they predict the occurrence of only one radio burst in each event. "If the radio burst is generated during a cataclysmic event that destroys the source, then we would expect to see only one burst per source," says Laura Spitler. Indeed, only single bursts were observed in the years right after their discovery – until news of the first "repeater" burst, called FRB 121102, was reported online in 2014. "This disproved all of the models explaining FRBs as the result of a catastrophic event," says Spitler.

FRB 121102 (which was also discovered at the Arecibo Observatory) was subsequently monitored by the researchers using the Very Large Array in New Mexico. After 80 hours of observation time, they registered nine bursts and determined the source's position to within one second of arc. At this position in the sky, there is a permanently radiating radio source; optical images show a faint galaxy about three billion light-years away. With a diameter of only 13,000 light-years, this galaxy is a dwarf; the Milky Way is about ten times larger. "However, many new stars, and perhaps even particularly large ones, are being born in the galaxy, and this might be a clue as to the source of the radio bursts," says Spitler.

She is referring to the possibility that FRBs may be pulsars – cosmic lighthouses that regularly emit radio radiation. This brings neutron stars back into play, because pulsars are rapidly rotating neutron stars that have strong magnetic fields. If the rotational and the magnetic axes of such an object are misaligned, a light-house like, bundled radio beam can be produced. Each time this celestial spotlight sweeps across the Earth, astronomers measure a short pulse.

The bursts from most radio pulsars are too weak to be detected from a great distance. However, short and extremely strong "giant pulses" are another matter. Born in a supernova explosion observed in 1054 AD, the Crab Pulsar is a textbook example of this type of astronomical object. Its giant pulses would be visible even from neighboring galaxies.

"One promising model suggests that FRBs are similar in nature to the Crab Pulsar, but they originate from extragalactic neutron stars that emit much larger pulses and are much rarer. Or perhaps they are younger and more energetic than the Crab Pulsar," says Spitler. "FRB 121102's home galaxy fits this model, as it has the potential to produce just the right type of stars that become neutron stars at the end of their lives." But whether this model is correct is still literally "written in the stars." Insight into their cause is not getting any easier, but observations are ongoing.

In the summer of 2019, for instance, the European VLBI Network of radio telescopes examined another repeater. During the five-hour observation period, FRB 180916.J0158+65 emitted no fewer than four radiation bursts, each lasting less than two milliseconds. Recently, the researchers also identified a roughly 16-day rhythm: for four days at a time, the source emits one or two bursts every hour then goes silent for twelve days. The source of this radio burst is in a spiral galaxy about 500 million light-years away. Even though such a distance is truly "astronomical," this object is the closest source ever observed. The findings also revealed that stars are evidently born at a high frequency in the vicinity of the burst.

Its position in the galaxy differs from that of all the other bursts investigated so far. FRBs, in conclusion, can apparently flare up in all kinds of cosmic regions and diverse environments. "This is just one of the reasons why we still do not know whether all bursts have the same type of source or are generated by the same physical processes," says Spitler. "Their origin remains a mystery."

←

GLOSSARY

EUROPEAN VLBI NETWORK
A network of radio telescopes located primarily in Europe and Asia. The network uses interferometry to link up the telescopes to form an enormous virtual telescope with an extremely high resolution.

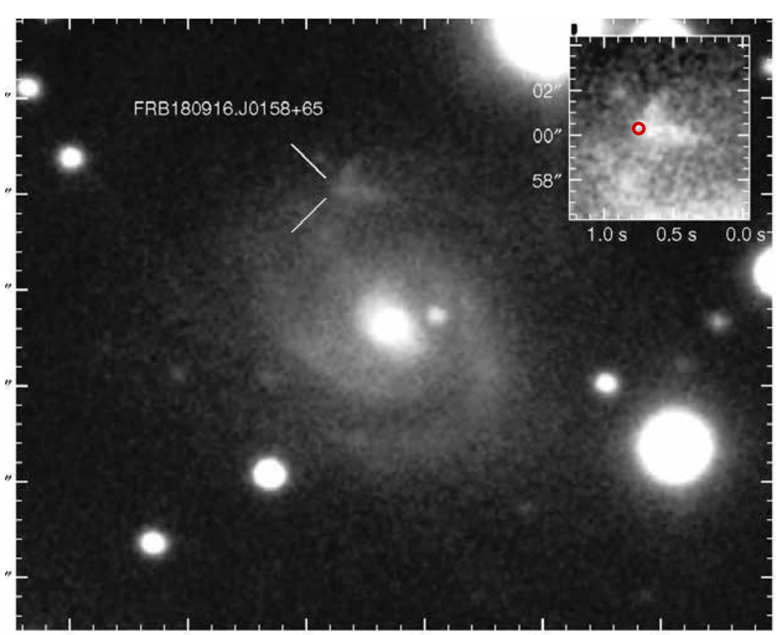

IMAGE: B. MARCOTE ET AL. / NATURE 2020

Fast radio burst: optical image of the source galaxy of the burst FRB 180916.J0158+65, obtained using the Gemini North telescope in Hawaii. The contrast in the magnified section has been enhanced, revealing the galaxy's star-formation region where the burst was discovered. Its position is marked by a red circle.